Ecological Characterization of a Lacustrine Environment of Community Interest: Case of Lake Kossou (Ivory Coast)

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Abstract: ***The Wetland Fish Index (WFI), for monitoring the water quality of Lake Kossou based on the associations observed between fish and environmental variables, has been developed. To this end, from February to June 2009, monthly experimental fishing was carried out at four stations using two batteries of monofilament nets with mesh sizes ranging from 15 to 60 mm, and physico-chemical parameters were measured in situ using portable digital display devices of the Waterproof type. Data on fish as well as physico-chemical parameters of each station were used in order to develop this ichthyological index of the different stations of Lake Kossou. A partial canonical correspondence analysis was used to order the fish species along the axes, in order to explain anthropogenic disturbances based on physico-chemical parameters. This analysis shows that, despite the good organisation of the Konsou population, the water at this station is more disturbed, with an ichthyological index of 2.32.***

Keywords: biological indicators, fish population, fisheries, Lake Kossou, Ivory Coast

1. Introduction

Water is an essential natural resource for perpetuate life on earth. It plays a central role in the development of human civilizations and in that to constitute aquatic ecosystems, therefore of sheltering living beings [**1**]. Lakes and water bodies, often located in peri-urban regions, can be an important resource for the city (drinking water supply), play a primary role in leisure activities and, in some cases, present an essential heritage value. Unfortunately, these ecosystems can fail in their mission when they are agressed. Indeed, they may contain substances or micro-organisms which, by their nature and/or concentration, can prove undesirable or even toxic [**2**]. In addition, disturbances of anthropogenic origin (fishing, pollution, human construction) and/or natural disturbance (upwelling, flooding of plains, climate change) can influence the dynamics of stocks and fisheries [**3**]-[**4**] as well as the diversity, productivity and sustainability of these environments [**5**]. However, fishing is one of the main human activities that affect aquatic ecosystems [**6**].

In Ivory Coast, continental fishing is based on a set of lake fisheries, the main ones being the lakes of Buyo, Ayamé I, Taabo, Fayé and Kossou. This last, Lake Kossou, has been the subject of several scientific studies [**7**]-[**8**]-[**9**]-[**10**]-[**11**]. However, there are almost no study that deals with biotic integrity of Lake Kossou, which is nevertheless an environment where several human activities are carried out, the most important of which is fishing. **[11]** found a drop in fish production from 2012 onwards. Lowering in catches observed in certain fisheries in the Kossou dam imposes today need to assess the various pressures influencing the productivity of this lake system. Thus, this study would like, through biological indices, to evaluate the effects of fishing and to determine the water quality of Lake Kossou based on the associations observed between fish and environmental variables.

2. Materials and methods

2.1. Study area

Lake Kossou (Figure 1) is a hydroelectric dam lake. It was built on the main course of the Bandama River 296 km from the mouth in 1971. Its length is 180 km with an area of 900 km^2 **[12]**. Located at an altitude of 203 m between latitudes 6°57' and 8°08' north and longitudes 5°42' and 5°49' west in the Yamoussoukro district, [**12**], it is bordered to the north by departments of Béoumi and Sakassou, to the south by departments of Yamoussoukro and Bouaflé, to the west by department of Zuénoula and to the south-east by the department of Tiébissou [**11**]. Several agricultural activities (yams, bananas, cassava, rice, cocoa and coffee) are practiced around lake [**13**]. Next to, fishing and artisanal search for gold are exercised on the river. Ichtyofauna population of Lake Kossou is dominated by Cyprinidae, Cichlidae, Morrnyridae, Clupeidae, Claroteidae, Schilbeidae and Alestidae **[14]**. [**15]** observed macrophyte species of which *Polygonumsenegalense* (Polygonaceae), *Eichhorniacrassipes* (Pontederiaceae), *Pistia stratiotes* (Araceae), *Ceratophyllumdemersum* (Ceratophyllaceae), *Vallisneriaethiopum* (Hydrocharitaceae) and *Nymphaea lotus* (Nymphaeaceae). Phytoplankton population of the lake is composed of the following classes: Bacillariophyceae, Synurophyceae, Chlorophyceae, Conjugatophyceae, Euglenophyceae, Dinophyceae and Cyanophyceae [**16**].

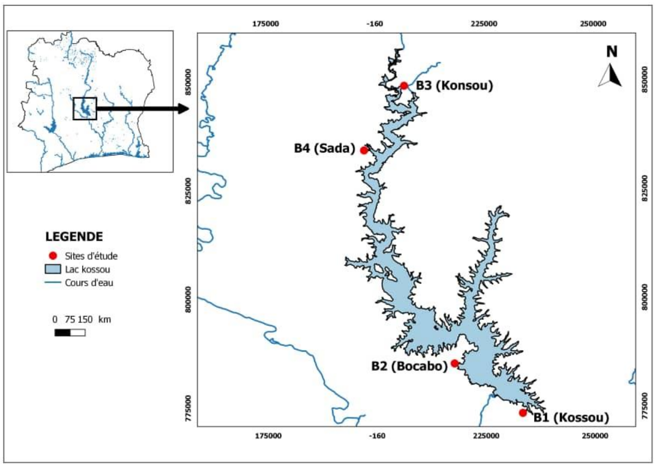

Figure 1: Geographical situation of Lake Kossou and sampling stations (Ivory Coast)

2.2. Measurement of physico-chemical parameters

Physico-chemical parameters were measured monthly between February and June 2009 using a conductivity meter, an oximeter and a pH meter. In the field, the devices, after they are switched on, were calibrated and their respective probes immersed in the first 50 centimetres of water. Measurements were taken in the morning between 7 a. m and 8 a. m. and between 12 and 1 p. m. during the day in situ. Depending on the device used, the value of the measured parameter is automatically displayed on the screen and this was raised after stabilization. For depth and transparency of the water, they were determined respectively using a graduated rope weighted in metres and the Secchi disk.

2.3. Fish fauna sampling

Experimental fisheris were carried monthly over a period February to June 2009 using a battery of 19 monofilament gill nets. Gill nets set at 5 p. m. and visited at 7 a. m. for night-time fishing, then revisited and removed at 12 p. m. for daytime fishing. Sampled fish were identified according to [**17**], [**18**] and [**19**] keys, counted, measured and weighed.

2.4. Data analysis

Data collected were analyzed respectively using numerical (N)and weight (P) percentages on the one hand

$$N = \frac{n}{Nt} \times 100 \qquad (1)$$

$$P = \frac{p}{Pt} \times 100 \qquad (2)$$

and on the other hand, using biological indices of Shannon-Weaver biological and equitability.

$$H' = -\sum pi \log_2 pi \qquad (3)$$

$$E = \frac{H'}{\mathrm{Log2}\ S} \qquad (4)$$

Shannon and Weaver's specific diversity index (H') measures the degree of stand organization. It is a value between 0 and 5 [**20**]. Equitability (E) allows you to appreciate the quality of this organization [**21**]-[**22**]. It varies between 0 and 1. These two indices were calculated from numbers using Past 2.0 software.

The Wetland Fish Index (WFI) [**23**]-[**24**] was used to define the ecological quality of the water Lake Kossou. Firstly, it was carried out on basis of the abundances of various species collected and environmental variables, a partial canonical correspondence analysis (pCCA), using the CANOCO 4.5 program. Values for tolerance (U) and niche width (T) [**25**] were assigned to species on the graph from the pCCA. Each harvested species was first assigned a value of U corresponding to its position on the x-axis, then value of T was assigned according to the previously assigned value of U. The value of U = 5 reflects an intolerant species, is assigned to a species at the negative end of axis 1. On the other hand, a value of U = 1 (tolerant species) indicates that the species is towards the positive end of axis 1. Intermediate values (2, 3 or 4) were assigned to all other remaining species, depending on their position along axis 1. Furthermore, when a species has a U value of 5 or 4, the corresponding T value is 3. This means that the ecological niche is not wide. For values of U = 1 or 2, the value of T = 1 (wide ecological niche) and the value of U = 3, that of T = 2. Secondly, the fish index for Lake Kossou was calculated for the four sampling stations using the following formula:

$$WFI = \frac{\sum Y_i T_i U_i}{\sum Y_i T_i} \qquad (5)$$

Where Yi = log10 abundance (log (x + 1)) of species i, Ti = value from 1 to 3 (indicating niche breadth) and Ui = value from 1 to 5 (indicating tolerance of degradation).

2.5. Statistical data processing

The Student's t-test is a parametric test for evaluating the differences between the means of two groups, dependent or not, and the mean of a group with one constant. The test is said to be significant for a probability value less than 0.05 ($p < 0.05$). Nature of the hypothesis (one-or two-sided) determines the areas of acceptance or rejection of the null hypothesis [**26**]. Student's t-test was used to compare the means of physico-chemical characteristics, specific diversity indices of Shannon-Weaver and of Equitability as well as the ichthyological indices between the different stations of Lake Kossou. This test was carried out using STATISTICA software version 7.1. A partial canonical correspondence analysis (pCCA) was carried out to order the abundances of the different species collected and the environmental variables on the x-axis, using the CANOCO 4.5 program [**25**].

3. Results

3.1. Physico-chemical characteristics

During this study, six environmental variables (temperature, hydrogen potential, dissolved oxygen, conductivity, depth and transparency) were measured monthly (**Table I**).

Average minimum temperature was observed in Bocabo (28.35°C) and the maximum in Konsou (31.35°C). Lowest pH value (7.06) has been registered at Kossou station and the highest (8) at Sada station. Extreme values of the rate of dissolved oxygen of water (min = 5.75 mg/l and max = 6.39 mg/l) were registered respectively, in Kossou and in Sada. Low rate of conductivity was measured at Sada station (74.95 µS/cm) and the highest at Konsou station (86.75 µS/cm). Overall, Konsou station is the deepest at 3.45 m and the shallowest is Sada station at 2.01 m. Lowest mean water transparency value (60 cm) was measured at the Sada station, and the highest (150 cm) at Bocabo. Comparison of physico-chemical variations by station indicated that there was a significant difference ($p < 0.05$) between the four stations.

Table I: Values (mean ± standard deviation) of environmental variables measured in the various stations of Lake Kossou from February to June 2009 (Côte d'Ivoire)

Stations	WT (°C)	Hp	O_2 (mg/l)	Cnd (µS/cm)	Dep (cm)	Transp (cm)
Kossou	28, 45	7, 06	5, 75	77	302	115
Bocabo	28, 35	7, 22	5, 84	77	303	150
Konsou	31, 35	7, 32	5, 99	86, 75	345	130
Sada	30, 80	8	6, 39	74, 75	201	60
Average	29, 73 ± 1, 2	7, 4 ± 0, 35	5, 99±0, 28	78, 87±28, 8	287, 5± 83	113, 75±78

WT: Water Temperature; Hp: Hydrogen potential; O2: Dissolved oxygen; Cnd: Conductivity; Dep: Depth; Transp: Transparency

3.2. Fish population

3.2.1. Quantitative inventory

A total of 33 species, including two introduced species (*Oreochromis niloticus* and *Heterotis niloticus*), were collected from February to June 2009 at stations on Lake Kossou (**Table II**). These species belong to six orders: Clupeiformes, Osteoglossiformes, Characiformes, Cypriniformes, Siluriformes and Perciformes. These orders are divided into thirteen families and twenty-three genera. The highest species richness was registered at Konsou (25 species). In contrast, the lowest species richness was obtained at the Bocabo station (9 species). Distribution analysis (Table II) shows six species common to all four stations (*Enteromius macrops*, *Hemichromis bimaculatus*, *Hemichromis fasciatus*, *Chrysichthys nigrodigitatus*, *Coptodon zillii*, and *Pellonula leonensis*). The species *Petrocephalus bovei*, and *Sarotherodon melanotheron* were only collected in Kossou. On the other hand, *Papyrocranus afer*, *Marcusenius ussheri*, *Mormyrops anguilloides*, *Heterotis niloticus*, *Schilbe mandibularis*, *Schilbe intermedius*, *Ctenopoma petherici* and *Malapterurus electricus* are present only at the Konsou station, and *Enteromiusablabes* at the Sada station. 1299 fish were caught, including 567 in Kossou station, 282 in Bocabo, 226 in Konsou and 224 at Sada. Different numerical proportions per station were calculated (**Figure 2**). At the Kossou station, *Enteromius* sp. (34%) and *Petrocephalus bovei* (23%) are the most abundant species. For the population at the Bocabo station, species C. nigrodigitatus (22% of workforce), Chromidotilapia guntheri (17%), Hemichromis bimaculatus (15%), C. zillii (14%) and P. leonensis (12%) were most important. At the Konsou station, *Parailia pellucida* and *E. macrops* dominate the population with a percentage of 22% each.

Table II: Taxonomic composition and distribution of fish species sampled in various stations on Lac de Kossou from February to June 2009

Orders	Families	Species	Ko	B	K	S
Clupeiformes	Clupeidae	*Pellonula leonensis*	+	+	+	+
Osteoglossiformes	Arapaimidae	*Heterotis niloticus*			+	
	Notopteridae	*Papyrocranus afer*			+	
	Mormyridae	*Marcusenius senegalensis*		+	+	
		Marcusenius ussheri			+	
		Mormyrops anguilloides			+	
		Petrocephalus bovei	+			
		Pollimyrus isidori			+	+
Characiformes	Alestidae	*Brycinusimberi*			+	+
		Brycinus longipinnis			+	+
Cypriniformes	Cyprinidae	*Enteromiusablabes*				+
		Enteromius macrops	+	+	+	+
		Enteromius sublineatus	+			+
		Enteromius sp.	+			
		Labeocoubie			+	+
Siluriformes	Claroteidae	*Auchenoglanis occidentalis*	+	+		+
		Chrysichthys maurus	+			+
		Chrysichthys nigrodigitatus	+	+	+	+
	Schilbeidae	*Parailia pellucida*			+	+

		Schilbe intermedius			+	
		Schilbe mandibularis	+		+	
	Clariidae	*Clarias anguillaris*			+	+
	Malapteruridae	*Malapterurus electricus*			+	
	Mochokidae	*Synodontis punctifer*			+	+
		Synodontis bastiani			+	+
Perciformes	Cichlidae	*Chromidotilapia guntheri*	+	+		+
		Hemichromis bimaculatus	+	+	+	+
		Hemichromis fasciatus	+	+	+	+
		Oreochromis niloticus			+	+
		Sarotherodon galilaeus			+	+
		Sarotherodon melanotheron	+			
		Coptodon zillii	+	+	+	+
	Anabentidae	*Ctenopoma petherici*			+	
6	13	33	14	9	25	21

Ko: Kossou; B: Bocabo; K: Konsou; S: Sada

Next come, *Pollimyrus isidori* (17%) and *Brycinus longipinnis* (15%). At the level Sada station, the most important species is *H. fasciatus* (24% of workforce), followed by *C. nigrodigitatus* and *C. zillii* (16% each), *E. macrops* (12%) and *H. bimaculatus* (11%).

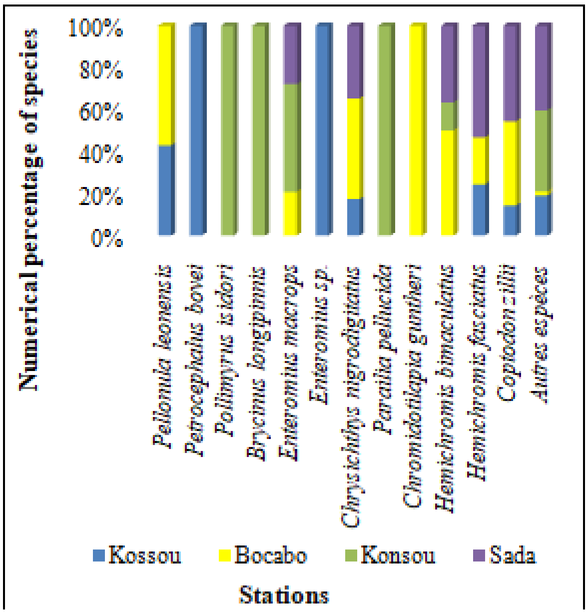

Figure 2: Numerical percentage of fish species in Lake Kossou stations from February to June 2009

3.2.2. Diversity of fish populations

Values of Shannon-Weaver diversity index (H') and equitability (E) the ichthyological populations were calculated on the basis of species abundance (**Table III**). The highest values of Shannon index (H') were obtained in the Sada (Ha' = 2.27) and Konsou (Ha' = 2.23) stations. However, Equitability, both numerical and weight, was stronger at Bocabo (Ea = 0.88).

Furthermore, the Student t-test showed a statistically significant difference at Shannon-Weaver diversity index (H') and Equitability (E) of ichthyological populations calculated on the basis of species abundance between the four stations (Student, $p < 0.05$).

Table III: Shannon diversity index (H') and of equitability (E) of ichthyological populations at Lake Kossou stations from February to June 2009

Stations	abundance	
	H’	E
Kossou	1, 90	0, 72
Bocabo	1, 94	0, 88
Konsou	2, 23	0, 69
Sada	2, 27	0, 75

3.2.3. Assessment of water quality of Lake Kossou

3.2.3.1. Correlation species-environmental variables

Influence of environmental variables on the distribution of fish species sampled in Lake Kossou was highlighted by canonical partial correspondence analysis (pCCA) (**Figure 3**). Axes 1 (λ1 = 58.6%) and 2 (λ2 = 25%), which expressed 83.6% of the cumulative variance values for species data, were considered in interpreting the results. Axis 2 identifies two groups of species. In the first group located on the positive side of axis 1, fish species (*Clarias anguillaris*, *Oreochroimis niloticus*, *Pollimyrus isidori*, *Heterotis niloticus*, *Brycinusimberi*, *Pollimyrus isidori*, *Synodontis punctifer*, *Parailia pellucida* and *Brycinus longipinnis*) are influenced by pH, conductivity, depth, dissolved oxygen and temperature at Konsou and Sada stations. Furthermore, the second group located in the negative part of axis 1 and associated with the Kossou and Bocabo stations, the distribution of fish species is influenced only by transparency. This second group encloses the species *Sarotherodon melanotheron*, *Petrocephalus bovei*, *Hemichromis fasciatus*, *Hemichromis bimaculatus*, *Pellonula leonensis*, *Enteromius macrops*, *Pellonula leonensis* and *Coptodon zillii*.

Optimal (U) and tolerance (T) values were assigned on the basis of models derived from environmental variables and fish species in the pCCA analysis (**Table IV**). They establish

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a relationship between the statistical mode of each species along the synthetic axes. U values assigned to species were linked to the position of a species on the first axis. The value of U = 5 (with T = 3) assigned to *Petrocephalus bovei*, *Sarotherodon melanotheron* and *Enteromius sp* in relation to their position on axis 1 of the pCCA (**Figure 3**) indicates that these species are intolerant to environment degradation. However, *Parailia pellucida*, *Pollimyrus isidori*, *Papyrocranus afer*, *Marcusenius ussheri*, *Mormyrops anguilloides*, *Brycinus longipinnis*, *Schilbe intermedius*, *Malapterurus electricus* and *Ctenopoma petherici*, which were located towards the positive end of axis 1, were assigned the value U = 1 (with T = 1). This means that this species is tolerant of environmental degradation. Intermediate values (2, 3 or 4) were assigned to all other remaining species, depending on their position along the pCCA 1 axis (**Figure 3**).

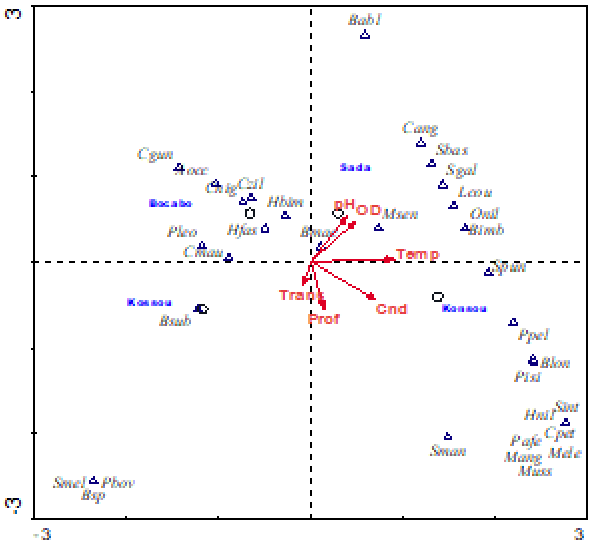

Figure 3: Influence of environmental variables on the distribution of fish species sampled at Lake Kossou stations

Pleo = *Pellonula leonensis;* Hnil = *Heterotis niloticus;* Pafe = *Papyrocranus afer;* Msen = *Marcusenius senegalensis;* Muss = *Marcusenius ussheri;* Mang = *Mormyrops anguilloides;* Pbov = *Petrocephalus bovei;* Pisi = *Pollimyrus isidori;* Bimb = *Brycinus imberi;* Blon = *Brycinus longipinnis;* Aabl = *Enteromius ablabes;* Emac = *Enteromius macrops;* Esub = *Enteromius sublineatus;* Esp = *Enteromius* sp. ; Lcou = *Labeo coubie;* Aocc = *Auchenoglanis occidentalis;* Cmau = *Chrysichthys maurus;* Cnig = *Chrysichthys nigrodigitatus;* Ppel = *Parailia pellucida;* Sint = *Schilbe intermedius;* Ssch = *Schilbe mandibularis;* Cang = *Clarias anguillaris;* Mele = *Malapterurus electricus;* Spun = *Synodontis punctifer;* Sbas = *Synodontis bastiani;* Cgun = *Chromidotilapia guntheri;* Hbim = *Hemichromis bimaculatus;* Hfas = *Hemichromis fasciatus;* Onil = *Oreochromis niloticus;* Sgal = *Sarotherodon galilaeus;* Smel = *Sarotherodon melanotheron;* Czil = *Coptodon zillii;* Cpet = *Ctenopoma petherici*

Table IV: Water quality values U (tolerance) and T (niches) for fish species, based on abundance data from Lake Kossou stations from February to June 2009 (Ivory Coast).

	Abundance			Abundance	
Species	U	T	Species	U	T
Pellonula leonensis	4	3	*Chrysichthys nigrodigitatus*	4	3
Heterotis niloticus	1	1	*Parailia pellucida*	1	1
Papyrocranus afer	1	1	*Schilbe intermedius*	1	1
Marcusenius senegalensis	2	1	*Schilbe mandibularis*	2	1
Marcusenius ussheri	1	1	*Clarias anguillaris*	2	1
Mormyrops anguilloides	1	1	*Malapterurus electricus*	1	1
Petrocephalus bovei	5	3	*Synodontis punctifer*	1	1
Pollimyrus isidori	1	1	*Synodontis bastiani*	2	1
Brycinus imberi	2	1	*Chromidotilapia guntheri*	4	3
Brycinus longipinnis	1	1	*Hemichromis bimaculatus*	3	2
Enteromius ablabes	3	2	*Hemichromis fasciatus*	3	2
Enteromius macrops	3	2	*Oreochromis niloticus*	2	1
Enteromius sublineatus	4	3	*Sarotherodon galilaeus*	2	1
Enteromius sp.	5	3	*Sarotherodon melanotheron*	5	3
Labeo coubie	2	1	*Coptodon zillii*	4	3
Auchenoglanis occidentalis	4	3	*Ctenopoma petherici*	1	1
Chrysichthys maurus	4	3			

3.2.3.2. Ichthyological index of lake stations

The abundance values of the species as well as the values of tolerance and of the extent of the niche were used for the calculation of the fish index in the different stations of Lake Kossou. The Kossou station has the highest index value (4.14). This value decreases up to the Konsou station (2.32) which has the lowest value (**Table V**). The results, derived from the calculation of the Wetland Fish Index (WFI), showed the existence of a pollution gradient from Konsou (stressed environment, poor water quality) to Kossou (stable environment, less stressed, good water quality). Student's t-test showed a statistically significant difference at WFI values between the Kossou Lake stations ($p < 0.05$).

Table V: Fish index values the Lake Kossou stations from February to June 2009 (Ivory Coast)

Stations	Fish Index
Kossou	4, 14
Bocabo	3, 68
Sada	3, 24
Konsou	2, 32

4. Discussion

Surface water quality appreciation is based on the measurement of physico-chemical parameters as well as the presence or absence of aquatic organisms, indicators of a more or less good water quality. Also, ecological quality of Lake Kossou was determined relying on certain of physico-chemical parameters such as pH, dissolved oxygen, conductivity, temperature, depth and transparency, as well as fish peuplements. The latter, according to **[27]**, can provide original information due to the ability of these organisms to integrate environmental variability at different spatial scales. The total abundance of the different species making up the stand was used to assess the environmental quality. Analysis of the Fish Index (FI) results for Lake Kossou showed that the ecological quality of the water in this environment varied from one station to another. Thus, the lake would be more disturbed at the Konsou station (FI = 2.32) despite good specific richness and diversity (SR = 25; H'= 2.23; E = 0.69); clearly better quality (FI = 4.14) at the Kossou station where specific richness and diversity (SR = 14; H'= 1.90; E = 0.72) are low. Indeed, the total number of species generally decreases with environmental degradation **[28]**. But, in the case of eutrophication, the resulting increase in productivity can eventually engender an increase in specific richness **[29]**. These results could be explained by the high temperature and conductivity recorded at the Konsou station, favoring excessive dissociation of dissolved salts, which would engender an increase in ions **[30]**. However, the presence of ions has often been used as an indicator of pollution, and their excessive presence in water has harmful effects on the growth of aquatic flora and fauna **[31]** and concerns about fish conservation **[32]**. Furthermore, some authors as **[33]** and **[34]** affirm that wetlands can be classified according to the degree of anthropogenic disturbance due to increased nutrient elements, water turbidity, temperature and conductivity, leading to deterioration of the water quality. Like specific richness, eutrophication can generate to an increase in the number of individuals **[35]**. Wetland degradation leads to changes in the fish community **[33]**. Also, remarks we that at the Konsou station, the fish peuplement is mainly dominated by dwarf species, *Parailia pellucida*, *Enteromius macrops*, *Brycinus longipinnis* and *Pollimyrus isidori*, which account for 76% of the total population. These strategy species, low biomass, have a great capacity for adaptation in the face of ecosystem disturbances an early sexual maturity and an intrinsic rate.

5. Conclusion

The man by his multiple activities has a significant impact on aquatic ecosystems, such as organic and chemical pollution by agriculture and industry, which modifies oxygen solubility and biodiversity. All these factors can have irreversible consequences, leading to a decrease in biodiversity and the disappearance of certain species. This work, carried out on Lake Kossou, showed that the Konsou station has good abiotic parameters and the highest specific richness compared with the other stations. A total of 33 species were collected at all the lake's stations, including 25 species at the Konsou station. However, the results of the fish index show that the water at the Konsou station is more disturbed by anthropogenic activities.

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